

University of Groningen

Efficient morphological tools for astronomical image processing

Moschini, Ugo

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version

Publisher's PDF, also known as Version of record

Publication date:

2016

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Moschini, U. (2016). *Efficient morphological tools for astronomical image processing*. [Thesis fully internal (DIV), University of Groningen]. University of Groningen.

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Efficient Morphological Tools for Astronomical Image Processing

Ugo Moschini



Netherlands Organisation for Scientific Research

The research work described in this thesis was carried out at the Intelligent Systems group of the Johann Bernoulli Institute for Mathematics and Computer Science, University of Groningen, The Netherlands. This work was financially supported by the Netherlands Organisation for Scientific Research (NWO) under project number 612.001.110.

Cover background: VISTA gigapixel mosaic of the central parts of the Milky Way. Id: eso1242. Credit: ESO/VVV Survey/D. Minniti. Acknowledgement: Ignacio Toledo, Martin Kornmesser.

Front cover detail: photo of a tea plantation taken by the author in Darjeeling, India. The whole plantation is made of small tea shrubs: likewise, the parallel construction of a max-tree occurs by merging together the small sub-trees computed by the threads.

Printed by Ipskamp Drukkers BV, Enschede, The Netherlands.

ISBN: 978-90-367-8848-9 (printed version)

ISBN: 978-90-367-8846-5 (digital version)



university of
groningen

Efficient Morphological Tools for Astronomical Image Processing

PhD thesis

to obtain the degree of PhD at the
University of Groningen
on the authority of the
Rector Magnificus Prof. E. Sterken
and in accordance with
the decision by the College of Deans.

This thesis will be defended in public on
Friday 13 May 2016 at 12.45 hours

by

Ugo Moschini

born on 14 February 1983
in Pisa, Italy

Supervisors

Prof. N. Petkov

Prof. S.C. Trager

Co-supervisor

Dr. M.H.F. Wilkinson

Assessment Committee

Prof. S.T. Acton

Prof. J.B.T.M. Roerdink

Prof. P. Salembier

to my grandma Nonna Vera,
and her beloved Firenze.

Contents

List of Figures	v
List of Tables	vi
List of Algorithms	vii
Acknowledgements	ix
1 Introduction	1
1.1 Scope	2
1.2 Thesis organization	5
2 Mask Connectivity by Viscous Closings: Linking Merging Galaxies without Merging Double Stars	7
2.1 Introduction	8
2.2 Second-generation connectivity	9
2.3 Standard and Viscous operators	11
2.4 Experiments and Discussion	13
2.4.1 Evaluation of the experiments	14
2.4.2 A visual evaluation	17
2.5 Conclusions	18
3 Improved Detection of Faint Extended Astronomical Objects through Statistical Attribute Filtering	21
3.1 Introduction	22
3.2 Background estimation	23
3.2.1 Is a constant a good fit?	26
3.2.2 Comparison of the background estimate w.r.t. SExtractor	28
3.3 Connected filtering on a max-tree structure	29
3.4 Identifying significant nodes	30
3.4.1 Significance test 1: power given area of the node.	31
3.4.2 Simulating distributions	32

3.4.3	Significance test 2: powerAlt given area and distance. . .	32
3.4.4	Significance test 3: powerAlt given area.	33
3.4.5	Significance test 4: powerAlt given area with smoothing . .	34
3.4.6	Testing the nodes	34
3.4.7	Discussion on the significance level α	35
3.5	Finding objects	35
3.5.1	Moving object markers up: parameter λ	35
3.6	MTOObjects vs Source Extractor	37
3.6.1	Object detection	38
3.6.2	Object fragmentation	40
3.6.3	Dust lanes and artifacts	41
3.7	Speed performance	42
3.8	Conclusions and future work	43
4	A Hybrid Shared-Memory Parallel Max-Tree Algorithm for Extreme Dynamic-Range Images	45
4.1	Introduction	46
4.2	The max-tree structure	47
4.3	State of the art sequential algorithms for XDR images	48
4.4	Two important max-tree algorithms	49
4.4.1	The Tarjan's union-find algorithm	49
4.4.2	The sequential Berger algorithm.	50
4.4.3	The parallel hierarchical queue algorithm	53
4.5	Issues with possible parallel algorithms for XDR images	55
4.6	The parallel hybrid algorithm	56
4.7	The <i>pilot</i> max-tree	58
4.8	The refinement stage	60
4.8.1	Intensity $\bar{f}(q) \in H_i$	62
4.8.2	Intensity $\bar{f}(q) \notin H_i$	62
4.9	Thread-safety and correctness	63
4.10	Time complexity and memory use	64
4.11	Performance testing	65
4.11.1	Performance tests on simulated images	67
4.11.2	Considerations on completion time and speed-up	69
4.11.3	Performance tests on real-world images	71
4.12	Conclusions	73
5	Towards Better Segmentation of Large Floating Point 3D Astronomical Data Sets: First Results	75
5.1	Introduction	76
5.2	Building max-trees of floating point data sets in parallel	78

CONTENTS

5.3	Attribute filter for astronomical object segmentation	78
5.4	Segmentation of 3D radio cubes	79
5.5	Performance testing	82
5.6	Conclusions	82
6	Concurrent Computation of Connected Pattern Spectra for Very Large Image Information Mining	85
6.1	Introduction	86
6.2	Connected filters	88
6.2.1	The max-tree structure	88
6.2.2	Connected Pattern Spectra	88
6.3	The parallel algorithm	89
6.4	Results	91
6.5	Discussion and Conclusions	92
7	Parallel 2D local pattern spectra of invariant moments for galaxy classification	95
7.1	Introduction	96
7.2	Max-tree object segmentation	97
7.3	Moments	98
7.4	Parallel local pattern spectra	99
7.5	Classifying galaxies: the experiment	100
7.6	Classification results and speed performance	101
7.7	Conclusions and future work	106
8	Viscous-Hyperconnected Attribute Filters: A First Algorithm	109
8.1	Introduction	110
8.2	Viscous-Hyperconnectivity class	111
8.3	Viscous-Hyperconnected filtering	113
8.3.1	The algorithm	114
8.4	Implementation notes	117
8.4.1	Eroding the input image	117
8.4.2	Computing the nodes within B_p and the common ancestor . .	117
8.5	Filtering results and performance	118
8.6	Edge preservation issues	120
8.7	Conclusions	120
9	Summary and Outlook	123
9.1	Summary	123
9.2	Outlook	126
	Samenvatting	129

CONTENTS

Bibliography	133
Research Activities	143
Curriculum Vitae	145

List of Figures

1.1	Example of connected filtering	3
2.1	A pair of interacting galaxies	9
2.2	Standard connectivity and mask connectivity	10
2.3	Effects of different mask images	11
2.4	Structuring element radius as a function of grey level	12
2.5	Measuring level of connectivity in two closely-spaced sources	14
2.6	The reconstructed level of the adjacent component	16
2.7	Reconstructed star with several mask images	17
2.8	Reconstructed galaxy with several mask images	18
3.1	Segmentations of merging galaxies	24
3.2	Rejection rate for squared flat tiles	26
3.3	Distribution of the β quantity	27
3.4	Image with β outliers	27
3.5	Other examples with β outliers	27
3.6	Average background estimate	28
3.7	SExtractor background estimate compared to the constant estimate	28
3.8	Object shape distortion when background is not constant	29
3.9	Peak components and max-tree	29
3.10	Rejection boundaries	33
3.11	Stars simulated by IRAF software	37
3.12	MTOBJECTS identifies better fainter outer regions and the nested objects	39
3.13	Comparison of objects with faint extended regions	39
3.14	Sparse and dense stars' grids	40
3.15	Fragmented simulated object	41
3.16	Fragmentation of a thin faint filament between two galaxies	41
3.17	Dust lanes	42
3.18	Artefacts	42
4.1	Field of view containing stars and two large interacting galaxies	46
4.2	Quantized image and its max-tree	47
4.3	Performance of existing parallel algorithms	54
4.4	Spatial and intensity partitions	56
4.5	Pixels are sorted according to their intensity	56

4.6	Descent through the hierarchy in the quantized tree	60
4.7	Merging union-find sets	63
4.8	Example images: ESO, PRAGUE, LOFAR	67
4.9	Performance on simulated images	68
4.10	Speed-up of each phase of the parallel algorithm	68
4.11	Completion time of each phase of the parallel algorithm	70
4.12	Performance with several <i>level root fixing</i> techniques	71
4.13	Performance and speed-up on real-world images	72
5.1	Segmentations of two merging galaxies	76
5.2	Radio cube segmentations	77
5.3	Radio cube segmentation by channel	80
5.4	Moment-0 image of the identified sources in the WSRT cube	81
6.1	Pattern spectrum of a remote sensing image	87
6.2	Performance and speed-up	92
7.1	Filament of a galaxy better segmented by our method	97
7.2	Examples of correct and wrong classification of galaxies	104
7.3	Difficult cases for the classifier	105
8.1	The leakage problem	111
8.2	Viscous hyper-connected components can overlap	112
8.3	Building and updating the max-tree of the cores	116
8.4	Attribute updating	117
8.5	Test images and performance	119
8.6	The edge-preserving issue	120

List of Tables

2.1	Parameters of the mask images	15
4.1	Simulated and real-world test images	66
4.2	Summary of the performance of the algorithms	66
7.1	Parameters of the pattern spectra	100
7.2	Classification with normalized ps of all the components	102
7.3	Classification with normalized ps of components larger than 4 px	102

7.4	Classification with not normalized ps of all the components	103
7.5	Classification with not normalized ps of components larger than 4 px	103
7.6	Execution time and speed-up values	106

List of Algorithms

3.1	ISFLAT: find flat tiles	25
3.2	SIGNIFICANTNODES: mark the nodes as significant	34
3.3	FINDOBJECTS: assign nodes to objects	35
3.4	MOVEUP: move the object identifiers up in the tree	36
3.5	MTOBJECTS: the whole segmentation algorithm	37
4.1	The Berger algorithm	50
4.2	Parallel hierarchical queue max-tree algorithm	51
4.3	FLOOD: recursive root-to-leaf flooding approach	52
4.4	CONNECT: procedure to merge trees	53
4.5	FLOOD_PILOT: build the <i>pilot</i> max-tree	58
4.6	KEEPLowESTLEVELROOT: stricter definition of level root	59
4.7	REFINEMENT: the parallel hybrid algorithm	61
6.1	CCAPS: create pattern spectrum in parallel	90
6.2	MAXTREEPATsPECTRUM2D: compute the local 2D ps	90
8.1	PROCESSTREE: process the max-tree of cores	115
8.2	COMPUTEATTRIBUTES: compute attributes of the viscous components	115

Acknowledgements

At the beginning of January 2012, I drove from Darmstadt to my new place in Groningen. It was indeed quite a long and lonely driving, but also the start of a longer four-year journey in which I worked on many interesting topics and in which I met just as many interesting and awesome new friends and colleagues.

I would like to start by thanking my supervisor and friend Michael Wilkinson. You have been an essential guidance when I moved my first steps in the realm of Mathematical Morphology. Your enormous knowledge (so much that I have recently nicknamed you “Wikipedia”) and your prompt availability contributed to make my work progress at a faster pace and led to engaging conversations. I felt as a real privilege to work with you. Our shared interests in astronomy, travelling, fossil hunting, ethnic cooking, history and your joyful attitude were at the basis of interesting coffee breaks and pleasant trips when attending conferences together. I must confess, though, that I never understood the rules of cricket, that you tried to explain to me so many times.

At first, I was a bit scared by having to deal with topics of astronomy, being new to the field. I want to thank my other supervisor Scott Trager from the Kapteyn Astronomical Institute for making me feel at ease since the beginning with clear explanations of previous findings and expert comments on the topics I worked on.

I am thankful to my promotor Nicolai Petkov for contributing to my personal and scientific growth, agreeing on all the courses, summer schools and conferences that I wanted to attend. Particularly, thanks to the “international workshops” that he organised, I gained confidence in presenting my work and I had the opportunity to meet many reputed scientists in an informal setting.

I would like to express my gratitude to the members of the assessment committee, the professors Scott Acton, Jos Roerdink and Philippe Salembier for their useful suggestions and valuable comments. It is funny to remember that precisely a journal paper by Salembier was the first article that I read on my very first day as a PhD.

I have been involved in some collaborations throughout my doctoral studies and I learned a lot by the interaction with professors, PhD colleagues and students. I would like to mention Georgios Ouzounis, Martino Pesaresi, Thijs van der

Hulst, Davide Punzo, Nadine Giese and the students Christiaan Arnoldus and Paul Teeninga. My thesis would have looked much less interesting without their contribution. I feel fortunate by having shared the academic environment with great scientists and nice colleagues: Michael Biehl, Paris Avgeriou, Marco Aiello, Doina Bucur, Mircea Lungu, the talks that you either held or organised and our conversations together were of inspiration to expand my horizons in many fields, also non-scientific. I would like to thank the university staff: Esmee Elshof, Desiree Hansen and Ineke Schelhaas, you have always been a support when I had to deal with bureaucracy and paperwork. I also thank Janieta de Jong for making the PhD progress meetings run as smooth as possible.

When I moved to The Netherlands, Groningen was not an unknown city to me: I knew already many people, friends and colleagues of my fiancée Tiziana. Céline, Mathieu, Felix, Julia, Miriam, Francesca, Claudia, Séb, Pat, Massimo, Matea, Krzyś, Johnny, with the more recent addition of Richard, Elena, Yagiz, Alwin and Jonas, how can I ever forget all the dinners, movie nights, football matches, gliding experiences, pub quizzes, funny and tiresome phd-movie makings, parties, Star Wars marathons and the juicy raclettes we had together in the last five years! I would like to tell my Indian friends Milon, Kiran, Suresh, Asish and Reema that it was amazing to get to know you and your culture both in The Netherlands and in India and host some of you in Italy. I can say that my discovery of Indian food was an unexpected and tasty surprise - and that is quite a compliment coming from an Italian.

At least once per week, I managed to overcome my laziness and go to play football. Many are the friends to remember, Dario, Riccardo, Marco, Alessandro, Diego, Francesco Pinto, Stephan with a honourable mention for “presidente” Francesco Mecozzi, the organiser of every match and, most importantly, a true friend and the best actor in my long-standing activity as editor of promotion phd-movies.

I am happy for the dear colleagues and friends that I met at the institute, in many cases sharing the same office. Baris, Ernest Mwebaze, Fred Kiwanuka, Andreas Neocleous (office mate and also flat mate for one year), Astone and Jiapan Guo (colleagues and athletes in the swimming pool), Laura Fiorini, the Spaniards Laura, Miguel, Manuel and Estefanía, the Brazilians Danilo, Daniel and Renata, George and Charmaine, Fritz, Fatimah, Petra, Mohammed Babai, Spyros, Christian, Sofia and the whole lot of Italian students from the University of Salerno, Walter, Vincenzo, Francesco, Nicola, Ilario, Raffaele, Peppe, Marco, we shared so many hours every day at the university, lunches, parties, coffees, road trips, conferences, house warming parties, cocktails, kart-racing, bike trips, beers and dinners with recipes from all around the world that in no way I can summarise everything in a few lines: just numbering your nationalities, I sum up to twelve or more different countries. You can all be sure that you have a special place in my heart and I cannot help but break into a smile whenever I remember all the things we did together. I want to thank also the colleagues “from the fourth floor”, Jasper, André and Matthew, re-

membering the conferences attended together and our lunches at the canteen in the first months of my PhD.

I want to give a heartfelt thanks to my paranymphs Nicola and Massimo: you both have been there since the very beginning. Nicola, I can say that I grew up as a scientist together with you, since you began the Erasmus in Groningen soon after I started. I will keep on studying the Neapolitan language, I promise. Massimo, both your spontaneity and your cooking skills made me feel like still in Italy. I will miss our time in Groningen and our coffee breaks at work. I send a big hug to your family, Anna, Nora and Corinna.

I would like to thank my Italian best friends Domi, Giacomo, Tommy, Robbi and the other expat Alessio, because every time I go back home, we meet up and it feels like I never left. A big hug (and of course a brotherly punch) goes to my brother Francesco, for all the fun we have together and for your capability to minimize problems that I sometimes tend to exaggerate. Mando anche un grande abbraccio a mamma, a babbo, agli zii Angela e Ale e a Nonna Vera, che mi hanno aiutato ogni giorno con consigli e trucchetti su ricette da cucinare, come pulire la casa, far funzionare le lavatrici, consigli finanziari e molto, molto altro. Hanno pure installato Whatsapp e Skype per starmi piu vicino. Ringrazio tantissimo anche Franca per avermi fatto sempre trovare un confortevolissimo posto per dormire e ottime cene al suo “ristorante”.

The biggest hug goes to my fiancée Tiziana. Our PhD studies crossed for about three years and it was great to finally live together in the same city and in the same house. Without you, I would not be the person I am now: thank you for encouraging me, long before this PhD experience, to pursue my dreams, even if that meant many times being far apart in different countries. Laughing together with you is one of those magic moments that Science alone will never be able to explain.

Ugo Moschini
Groningen
April 13, 2016

